PREDICTIVE MODELING OF ALTITUDE DECOMPRESSION SICKNESS IN HUMANS

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I. SUMMARY

This project consisted of the coding of data on 2,565 individual human altitude chamber tests. As part of a selection procedure designed to eliminate individuals who are highly susceptible to decompression sickness, individual aircrew members were exposed to the pressure equivalent of 37,000 feet and observed for one hour. Many entries refer to subjects who have been tested two or three times. This data contains a substantial body of statistical information important to the understanding of the mechanisms of altitude decompression sickness and for the computation of improved high altitude operating procedures. This report covers the first phase of a two-part project dedicated to encoding, reducing, analyzing and interpreting this experience.

Appropriate computer formats and encoding procedures have been developed and all 2,565 entries have been converted to these formats and stored on magnetic tape. A gas loading file has been produced. The data are ready for the analysis phase.

II. INTRODUCTION

A. Scope of the Project

Mission success and human safety in aerospace flight are affected by the onset of incapacitating events that can be expected to occur in the event astronauts in a spacecraft or space station or crew and passengers in an aircraft operating at high altitude are exposed to a sudden reduction in pressure without adequate pre-oxygenation. Decompression sickness, to be sure, does not pose a significant problem in current space mission where the cabin atmosphere consists primarily of oxygen at reduced pressure. However, this form of trauma must be accepted as a finite risk in space flights now in the planning stage where the operating atmosphere will be air at sea level. Thus, there exists a need to obtain precise insight into the course of events which may develop in the event of cabin pressure loss, the degree of anticipated crew incapacitation and the probability of the occurrence of such incapacitation with respect to age, weight, stature and other distinguishing characteristics of flight personnel.

Through the courtesies of Surgeon Captain J.S.P. Rawlins, O.B.E., R.N., we have been provided with the records of all manned decompression histories compiled between 1 January 1950 and 31 December 1962 in the course of administering the Royal Naval High Altitude Selection Test. These were collected by Surgeon Commander Ian H. Colley, O.B.E., R.N., of the Royal Navy Air Medical School. This test consists of decompressing men, without preoxygenation, from ground level to 37,000 feet within 10 minutes. Each individual is held at that altitude for 60 minutes unless the onset of decompression sickness forces a premature return to ground level. During ascent and at altitude the test subjects breathe oxygen by mask, and each subject is expected to complete three such altitude exposures on three consecutive days each time he takes the test.

Detailed decompression records have been processed for 2,135 individuals who have taken this High Altitude Selection Test. Of this total 1,734 took the test once, 372 twice and 29 three times yielding a total of 2,565 test results. Of this total 898 tests produced concisely documented signs and symptoms of altitude decompression sickness sufficiently severe to restrict the future flying activity of the affected personnel (classified as Category B and C). Tables 1 through IV provide a breakdown of the case histories available to us.

This wealth of clinical material represents an invaluable raw information base for predicting the most probably physiological outcome of the emergency decompression at altitude of a manned nitrogen-oxygen atmosphere system.

Under the terms of Contract NAS 2-6647, the data presented to us from the Royal Navy Air Medical School were to be reviewed and encoded into data files to provide access to this material. Our purpose was to derive from it statistically secured, time-related predictions of the probabilities associated with the onset of various symptoms of altitude decompression sickness and then developing severity that can be expected in the event of emergency pressure loss at altitude. We were then to evaluate these expected manifestations of decompression sickness in terms of their impact on mission success. This risk

TABLE I

Breakdown of Categories and Groups

Category	Pilots	Observers	R. Aircrew	Civilians	Others	Total
A	1342	226	30	27	42	1667
B	606	121	12	12	13	764
C	105	20	1	4	4	134
	2053	367	43	43	59	2565

TABLE II

Total by Years

Year	Pilots	Observers	R.Aircrew	Civilians	Others	Total
1950	50	-	-	-	8	58
1951	77	-	-	-	11	88
1952	100	-	-	-	1	101
1953	169	6	-	1	1	177
1954	241	32	-	2	1	276
1955	275	31	11	9	1	327
1956	178	38	-	3	1	220
1957	102	62	1	5	4	174
1958	149	64	3	-	14	230
1959	242	29	-	1	12	284
1960	196	42	9	9	3	259
1961	122	30	12	10	-	174
1962	152	33	7	3	2	197
	2053	367	43	43	59	2565

TABLE III

Total by Categories

Year	A	B	C	Total
1950	37	15	6	58
1951	61	22	5	88
1952	72	25	4	101
1953	114	52	11	177
1954	181	79	16	276
1955	218	94	15	327
1956	138	69	13	220
1957	104	66	4	177
1958	148	68	14	230
1959	202	70	12	284
1960	164	85	10	259
1961	115	50	9	174
1962	113	69	15	197
	1667	764	134	2565

TABLE IV

Breakdown by Categories and Years

Year	Pilots			Observers			R. Aircrew			Civilians			Others			Total
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	
1950	32	13	5	-	-	-	-	-	-	-	-	-	5	2	1	58
1951	54	20	3	-	-	-	-	-	-	-	-	-	7	2	2	88
1952	72	24	4	-	-	-	-	-	-	-	-	-	-	1	-	101
1953	108	50	11	5	1	-	-	-	-	-	1	-	1	-	-	177
1954	156	71	14	23	7	2	-	-	-	1	1	-	1	-	-	276
1955	176	85	14	24	6	1	9	2	-	8	1	-	1	-	-	327
1956	119	50	9	16	19	3	-	-	-	2	-	1	1	-	-	220
1957	63	38	1	33	27	2	1	-	-	4	-	1	3	1	-	174
1958	91	50	8	45	14	5	3	-	-	-	-	-	9	4	1	230
1959	173	59	10	18	10	1	-	-	-	-	-	1	11	1	-	284
1960	126	62	8	25	16	1	5	3	1	6	3	-	2	1	-	259
1961	84	31	7	18	11	1	9	3	-	4	5	1	-	-	-	174
1962	88	53	11	19	10	4	3	4	-	2	1	-	1	1	-	197
	1342	606	105	226	121	20	30	12	1	27	12	4	42	13	4	2565

assessment should be invaluable in the planning of emergency procedures for manned space missions flown in a nitrogen-oxygen environment.

B. Experimental Plan

In our original proposal we separated the work into two one-year phases. The first phase was to review the data available on the 2,135 individuals who participated in the High Altitude Selection Tests (HAST) of the Royal Navy, and to organize the data into different files categorized under Subject, Decompression, and Gas Loadings. Each of the associated files was then to be encoded onto magnetic disks for eventual storage in a more stable medium such as cards or magnetic tape.

Phase two of this project was to comprise the identification of the extent and format of the data analyses to be accomplished. This required the completion of Phase One, the statistical treatment of bio-medical data, the adaptation of existing programs and the writing of new computer programs and subroutines to effect the desired analyses, and the final analysis of the data using an IBM 370 digital computer system and a Honeywell H316 minicomputer system.

III. DESCRIPTION OF THE DATA

A. Gas Loading Calculations

In order to evaluate the decompression of the pilot population it was necessary to calculate the gas loadings at each minute of the flight for each of fifteen theoretical tissue compartments. A Fortran computer program called CALINERT02 was developed for this laboratory using a Honeywell H316 minicomputer.

CALINERT02 is a general purpose program which is used to evaluate any pressure-time profile regardless of whether the profile violates any boundary conditions. The program can follow three different gases in each of fifteen individual half-time compartments. The sum of Pi (partial pressure of all of the gases in the tissue) is also computed if the number of gases to be followed is greater than one. The Pi values are evaluated for each theoretical tissue compartment with the halftime value of $t_{1/2}$ using the following gas transport equations:

$$Pi = P_o + c(t-1/k) - (P_o - Pi_o - c/k)\, e^{-kt}$$

where

P_o Partial pressure of inert gas (breathing mixture)

Pi Partial pressure of dissolved inert gas (tissue)

c Rate of change of partial pressure of inert gas (P_o)

k Specific time constant $\ln\left(\frac{2}{t_{1/2}}\right)$

$t_{1/2}$ Half-life

The Fortran program CALINERT02 is included with the report and can be found in Appendix A. The gas loadings file is also included with the report and can be found in Appendix B.

B. Criteria for Decompression Incidents

Three categories were assigned to air crew members when they completed their H.A.S.T. course; these categories were defined as:

Category A. With no high altitude flying restrictions.

Category B. This includes all those who have to be brought to ground level before the end of one hour's exposure because of "bends." They are not allowed to fly above 30,000 feet in an unpressurized aircraft.

Category C. Into this group come all those who severely suffer from Decompression Sickness. This group is not allowed to fly above 30,000 feet at all.

Each man did three "runs"--each lasting for one hour--and depending on how they reacted, they were categorized either as A, B or C. They then came back every four years to do the same H.A.S.T. Course.

During each of the runs careful notes were written down into a master log book. The information contained in this notebook were physiological reactions to decompression from surface to 37,000 feet of altitude. Table V shows symbols used (but not adhered to fully) in recording the decompression incidents:

TABLE V

HD	Head	LL	Lower Leg
S	Shoulder	K	Knee
UA	Upper Arm	AN	Ankle
LA	Lower Arm	F	Foot
E	Elbow	B	Back
R	Wrist	A	Aches
H	Hand	T	Tickle
C	Chest	TN	Tingle
AB	Abdomen	PN	Pins and Needles
UL	Upper Leg	P	Pain
		S	Severe
RGL	Return to Ground Level	DNR	Descent Not Required
PG	Pain Gone at		

ALTITUDE IS MARKED IN BLACK

MINUTES AND SYMPTOMS IN RED

Because the amount of data was far more extensive than this original coding would permit, an expanded coding system was developed. We chose three criteria for decompression incidents:

1. Time of onset of decompression symptom.
2. Decompression symptom.
3. Location of decompression symptom.

The time was increased from the point at which the altitude reached 37,000 feet, in minutes. The decompression symptom is a three letter (alphanumeric) code. This code does not give a quantitative severity score to the symptom, because of the difficulty of assigning a proper number to each observation.

Decompression symptoms are listed in Table VI. The location of decompression symptoms is a four letter alphanumeric code indicating the exact position, when known, of the decompression symptom. More general categories are also included to allow ambiguity of location to be coded. Table VII shows locations of decompression symptoms.

TABLE VI

DECOMPRESSION SYMPTOMS

SYG	Symptom gone	CHO	Chokes
TIC	Tickle	CIC	Circulatory collapse
ICH	Skin itch	SYN	Syncope
TIN	Tingle	PAR	Paralysis
HTF	Hot flashes	SOB	Shortness of breath, difficulty in breathing
HOT	Hot	SWT	Sweating
CLD	Cold	COU	Coughing
NUM	Numbness	SCO	Scotoma
PIN	Pins & Needles	NYS	Nystigmas
RAS	Rash	CON	Convulsion
BLV	Blurred vision	TIT	Tightness
SIC	Sick	GAS	Gas
PAL	Pallor/pale	DST	Distention
DIZ	Dizzy	PRT	Parasthesia
FAI	Faintness	HYP	Hypoxic
DIS	Discomfort, uncomfortable	VOM	Vomit
SLP	Slight pain	ARD	Aerodontalgia
ACH	Aches	NOB	Nose bleed
PAN	Moderate pain	BLD	Blindness
SVP	Severe pain	CRA	Cramp
		STF	Stiffness

TABLE VII

LOCATION OF DECOMPRESSION SYMPTOMS

HEAD	Head	AXIL	Axilla
FORH	Forehead	RTAX	Right axilla
SNUS	Sinus	LTAX	Left axilla
LTSN	Left sinus	CLAV	Clavicle
RTSN	Right sinus	RTCL	Right clavicle
EAR	Ear	LTCL	Left clavicle
EYES	Eyes	PCMS	Pectoral anus
EYE	Eye	LTPM	Left pectoral anus
JAW	Jaw	RTPM	Right pectoral anus
RTJW	Right jaw	RIBS	Ribs
LTJW	Left jaw	ARMS	Arms
TOOH	Tooth	ARM	Arm
THRT	Throat	RTAM	Right arm
NECK	Neck	LTAM	Left arm
RTNK	Right neck	UPAR	Upper arms
LTNK	Left neck	RTUA	Right upper arm
CHST	Chest	LTUA	Left upper arm
SPNE	Spine	ELBW	Elbow
BACK	Back	ELBS	Elbows
UPBK	Upper back	RTEL	Right elbow
LWBK	Lower back	LTEL	Left elbow
COYX	Coccyx	RTLA	Right lower arm
SHLD	Shoulder	LTLA	Left lower arm
SHLS	Shoulders	FARM	Forearm (either side)
RTSH	Right shoulder	WRST	Wrist
LTSH	Left shoulder	RTWT	Right wrist

TABLE VII (CONT'D)

LOCATION OF DECOMPRESSION SYMPTOMS

LTWT	Left wrist	RTUL	Right upper leg
HAND	Hand (either side)	LTUL	Left upper leg
HNDS	Hands	LEG	Leg (right or left)
RTHD	Right hand	LEGS	Legs
LTHD	Left hand	RTLG	Right leg
RTFI	Right fingers	LTLG	Left leg
LTFI	Left fingers	RTKN	Right knee
RTTH	Right thumb	LTKN	Left knee
LTTH	Left thumb	KNEE	Knee
RTSD	Right side of body	KNES	Knees
LTSD	Left side of body	RTLL	Right lower leg
ABDM	Abdomen	LTLL	Left lower leg
LWAB	Lower abdomen	ANCL	Ankle
UPAB	Upper abdomen	ANKS	Ankles
HIP	Hip	RTAN	Right ankle
RTHP	Right hip	LTAN	Left ankle
LTHP	Left hip	RTFT	Right foot
ASS	Buttocks	LTFT	Left foot
LTAS	Left buttocks	TOE	Toe
RTAS	Right buttocks	TOES	Toes
GRON	Groin	RTTO	Right toe
RTGR	Right groin	LTTO	Left toe
LTGR	Left groin	BODY	Body

C. Problems in Conversion

The notebook which contains the data is quite well documented. However, there are a few entries which we could not interpret, such as--R = wrist or R = right, and also L = left or L = lower. When there was any doubt as to meaning we left the code as it was written and did not convert the code to the more detailed system. For example; for "LA," instead of writing LTAM (left arm) or FARM (lower arm or forearm), we left the entry LA.

On a dozen or so occasions we could not read the notations which were written. In all of those cases the notations were "comment" and not decompression symptoms.

IV. FILE DESCRIPTION

A file is a group of similar records containing data in either binary form or Binary Coded Decimal (BCD) form, and ends with an End of File (EOF). A record is a string of characters.

The five files are as follows:

1. Subject File
2. Repetitive Flight File
3. Gas Loadings File
4. Decompression Incident File
5. Comments File

All five files are coded and placed onto nine track digital magnetic tape. The recording density is 1600 bits per inch, phase encoded, in hexadecimal (base 16) form. The table of alphanumeric conversion to hexadecimal form is included as Appendix C. Data stored on tape in this manner is in "card images" and is in essence the same as if it were on cards. (Alternate ASCII code could easily replace the hexadecimal code, if required, with the IBM utility program IEBGENER.)

A. Subject File

The following information is included on each record in the subject file:

1.	Year:	Columns 1 - 2
2.	Subject:	Columns 3 - 5
3.	Age of subject:	Columns 7 - 8
4.	Weight of subject:	Columns 10 - 15
5.	Height of subject:	Columns 17 - 21
6.	Category upon completion:	Column 23

B. Repetitive Flight File

The following information is included on each record of the repetitive flight file:

1. Name: Columns 1 - 20
2. 1st set of runs: Columns 21 - 30
3. 2nd set of runs: Columns 31 - 40
4. 3rd set of runs: Columns 41 - 50

It is feasible to consolidate the Subject File and the Repetitive Flight File together for ease of reference. In that case the other one or two repetitive flights would appear with the name in the Subject File. In many cases information would be redundant and a tradeoff would have to be made as to the better of the two systems.

C. Gas Loadings File

This file applies to all flights conducted on the basic profile:

1. Time in minutes after reaching 37,000 feet altitude: Columns 1 - 10.
2. Gas loadings from compartment 1 - 7: Columns 11 - 80, 10 columns/loadings of the first record.
3. Gas loadings from compartment 8 - 15: Columns 1 - 80 on the next record, 10 columns/loading the tissue half-time in minutes based on nitrogen, for each of the fifteen theoretical tissue compartments in Table VIII. (1)

TABLE VIII. COMPARTMENT HALF-TIMES

Compartment #	Minutes
1	5.0
2	9.0
3	12.0
4	7.0
5	15.0
6	27.0
7	35.0
8	23.0
9	52.0
10	89.0
11	118.0
12	81.0
13	182.0
14	315.0
15	416.0

D. Decompression Incident File

Decompression incidents are each recorded in this file.

1. Year: Columns 1 - 2
2. Subject: Columns 4 - 6
3. Run: Column 8
4. Decompression Incident: Columns 10 - 69, 10 columns/incident

a) Time	TTx	Column X0	X = 1 to 6
b) Symptom	SSSx	Column X2	X = 1 to 6
c) Location	LLLLx	Column X5	X = 1 to 6

The format for each decompression incident in columns 10 - 69 is TTSSLLLL. That is, if the third incident were numbness in the right toes occurrence at 27 minutes after reaching altitude, columns 30 to 38 would be 27NUMRTTO.

5. Status: Columns 71 - 73

   RGL = Return to ground level, DNR = Descent (before 60 min. period) not required.
6. Pain gone: PG in columns 75 - 76
7. Altitude or time: Columns 78 - 80

Three columns are necessary; two digits of altitudes in thousands of feet or time in minutes and one alphanumeric, either F for feet or M for minutes. The entires are made in this manner because recordings in the original logbook are either minutes or altitude, but not both. In analysis a conversion profile can be used.

E. Comments File

COMMENTS FILE

1.	Year:	Columns 1 - 2
2.	Subject:	Columns 4 - 6
3.	Run:	Columns 8
4.	Comments:	Columns 10 - 80

Any alphanumeric is acceptable here. This file is primarily used in those flights which caused decompression sickness of a severe nature, categorized as "C". Any other facts or comments which could not be included in the Decompression Incident File are included in the comments file.

V. RESULTS

The data logbook prepared by Dr. Colley has been successfully transcribed in five separate but dependent files onto magnetic tape. Backup data is available on punched cards if catastrophic damage should result. A unique alphanumeric coding system was employed during conversion of the raw data to allow for a more flexible analytical base for future analysis. Because the original contract considered the analysis of this wealth of decompression data in the second phase, nothing more then encoding has been undertaken.

VI. ANALYTICAL CAPABILITIES

In performing the final analysis on this data it was originally proposed to use the IBM 360 system. This has since been replaced with a larger and more effective System 370. However, competition for this system led us to the development of a minicomputer based on a Laboratory File Management System. The LFMS revolves around a Honeywell H316 minicomputer with 12K words of 16 bits, ASR 33 teletype, a high speed paper tape reader, a real time clock, an analog to digital subsystem, a digital I/O subsystem, a medium speed printer and a magnetic tape system. The LFMS software includes a highly efficient magnetic tape operating system, a Fortran compiler, machine language assembler, a symbolic source update program, a debug program, a powerful Basic interpreter and all the necessary device drivers. The LFMS is capable of creating, storing, accessing, debugging and analyzing large files of data in either binary form or BCD form (binary coded decimal).

Through the use of the mag tape operating system we access both programs and data to be used in the programs. By calling for Basic,one can virtually write programs "on-line". This is a considerable improvement over the "batch" type operation which results from using a large computer dedicated to many other uses. It is our intention to use the LFMS for the major part of any future work done on this project.

VII. FUTURE ANALYSES

During the tedious conversion of raw data onto coding sheets, we have gained a great appreciation for the magnitude and thoroughness of the Royal Navy Air Medical School's work in performing the High Altitude Selection Test. The careful attention to profile, time and decompression symptoms has given us access to a wealth of knowledge as to predictability of altitude decompression sickness. Because of the large number of subjects that performed in the H.A.S.T., statistical analysis can yield a number of facts that could not easily be obtained otherwise. Such analyses could be:

A. Bends susceptability vs. subject parameters:
   1. Age - relative, and within the same subject.
   2. Weight - may vary between tests on the same subject.
   3. Height.

B. The most prevalent bends locations vs.:
   1. Subject.
   2. Time into flight profile, or the equivalent tissue gas loadings.
   3. Symptoms.

C. Symptomatology and time course of the development of symptoms as a function of:
   1. All the above parameters.
   2. Correlations with other symptoms such as coughing vs. skin rash.

When all these facts have been presented, the results might well provide correlations to the eventual detection of better decompression mechanisms. As a minimum the data will enable us to predict when a flyer is most likely to develop the bends. As a further benefit, analysis of the data might show that altitude decompression does not fit the "gas loading" approach to decompression computation. Conversely, this analysis could just as well lead to a new model if we can find common factors within the subjects which allow us to fit better a gas loading to a symptom, we might find a better scheme to decompress divers from excursions from hyperbaric habitats as well as to protect high altitude flyers and astronauts.

Decompression sickness remains a problem in aviation. A recent summary of USAF statistics(2) shows a high percentage of reported cases occurring at cabin altitudes of less than 25,000 feet. There is no way to assess the degree of involvement in air-crew members whose symptoms are relieved on descent and who do not subsequently file a report. A thorough statistical analysis of "captive" subjects such as those in the H.A.S.T. will provide relevant answers.

A large amount of carefully collected data has been moved one step further toward useful analysis in this program. It is our sincere desire that the information involved receive additional analysis.

C

VIII. REFERENCES

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A Pragmatic View of Decompression. In: <u>Proc. Fourth Symp. Underwater Physiol.</u>, edited by C.J. Lambertsen. New York: Academic Press, 1971.

2. Lewis, S.T.
Decompression Sickness in USAF Operational Flying, 1968-1971. <u>Aerospace Med</u>. 43:1261-1264, 1972.

APPENDIX A

CALINERT02 PROGRAM

The CALINERT 02 program determines the Pi values for each compartment (1-15), for any selected profile.

APPENDIX A

CALINERT02

```
C       CALCULATIONS OF INERT GAS PRESSURE FOR A 15 TISSUE SYSTEM.
C       D.J. KENYON AND M. FREITAG      28 MARCH 1972
C       CALINERT02  MODIFIED JULY 13 1972
        REAL K
        COMMON HT(3,15),PI(3,15)
        COMMON T(100),B(3,100),F(100),R(100)
        COMMON HEAD(36)
        READ(2,113) HEAD
  113   FORMAT(36A2)
   20   READ(2,101) K1,K2
  101   FORMAT(2I3)
        READ(2,102) ((PI(I,J),HT(I,J),I=1,3),J=1,15)
  102   FORMAT(6F7.1)
        READ(2,103) (F(N),T(N),R(N),(B(I,N),I=1,3),N=1,K2)
  103   FORMAT(3F7.1,3F7.4)
        WRITE(1,906) ((HT(I,J),I=1,3),J=1,15)
  906   FORMAT(3(5X,F7.1))
  302   TTOT=0.0
        TBOT=0.0
        L=1
        DO 91  N=1,K2
        TTOT=T(N)+TTOT
        PRES=F(N)+R(N)*T(N)
        IF(L.EQ.2)  GO TO 901
        L=2
        WRITE(1,114) HEAD
  114   FORMAT(H1,36A2)
        GO TO 902
  901   L=1
  902   IF(PRES.EQ.F(N))  GO TO 211
  210   WRITE(1,105) TTOT,PRES,R(N)
  105   FORMAT(21H0ELAPSED TIME EQUALS ,F9.1,4H MIN/16H PRESSURE EQUALS,
       1F7.1,6H MM HG/12H RATE EQUALS,F7.1,11H MM PER MIN/)
        TBOT=0.0
        GO TO 904
  211   TBOT=TBOT+T(N)
        WRITE(1,112) TTOT
  112   FORMAT(23H0ELAPSED TIME EQUALS   ,F7.1,4H MIN)
        WRITE(1,122) PRES,TBOT
  122   FORMAT(16H  TIME SPENT AT ,F7.1,13H MMHG EQUALS ,F7.1,4H MIN)
```

```
904 C1=B(1,N)*100.0
    C2=B(2,N)*100.0
    C3=B(3,N)*100.0
    WRITE(1,905) C1,C2,C3
905 FORMAT(1H ,9X,F7.2,8H % GAS 1,5X,F7.2,8H % GAS 2,5X,F7.2,
   18H % GAS 3)
212 WRITE(1,106)
106 FORMAT(1H0,
   161H             TISSUE         PI  VALUE           SUM     SUM     SUM/
   262H             COMPT.  GAS         GAS        GAS   OF PI   OF PI   OF PI/

   361H             NUMBER   1           2          3    MM HG    ATA     FSW/)
    DO 92  J=1,15
    PT=0.00
    DO 93 I=1,3
    RATE=R(N)*B(I,N)
500 IF(B(I,N).NE.0.00)  GO TO 510
    PO=0.00
    RATE=0.00
    GO TO 900
510 IF(F(N).GE.700.0)  GO TO 600
    PO=(B(I,N)*(F(N)-39.5))
    GO TO 900
600 PO=(B(I,N)*(F(N)-37.0))
900 K=0.693/HT(I,J)
    PI(I,J)=PO+(RATE*(T(N)-(1.0/K)))-(PO-PI(I,J)-(RATE/K))*
   1EXP(-K*T(N))
    PT=PT+PI(I,J)
 93 CONTINUE
    PTAT=PT/760.0
    PTFW=PTAT*33.0
    WRITE(1,109) J,(PI(I,J),I=1,3),PT,PTAT,PTFW
109 FORMAT(1H ,11X,I2,4F8.1,F8.3,F8.2)
 92 CONTINUE
    WRITE(1,903)
    WRITE(1,903)
903 FORMAT(1H0)
 91 CONTINUE
    END
$0
```

APPENDIX B

GAS LOADINGS FILE

These values represent the total nitrogen partial pressure (Pi) contained in each compartment (1-15), for each minute for 10 minutes of decompression to 37,000 feet and 60 minutes after arrival at altitude.

APPENDIX B

GAS LOADINGS FILE

PREDICTIVE MODELING OF DECOMPRESSION SICKNESS IN SPACECRAFT CABIN ATMOSPHERES, NAS 2-6697

TIME	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	503.50	535.50	545.90	523.90	552.30	563.70	567.10	561.20	570.70	573.90	575.00	573.50	576.20	577.10	577.40
2	438.40	495.80	515.30	474.50	527.40	549.50	555.90	544.60	563.20	569.50	571.60	568.60	574.00	575.90	576.50
3	381.60	459.10	486.40	429.80	503.50	535.50	545.00	528.40	555.70	565.00	568.30	563.70	571.80	574.60	575.50
4	332.20	425.10	459.10	389.30	480.80	522.00	534.40	512.70	548.40	560.70	565.00	558.90	569.70	573.30	574.60
5	289.20	393.60	433.30	352.60	459.10	508.70	523.90	497.50	541.10	556.30	561.70	554.20	567.50	572.10	573.60
6	251.80	364.40	409.00	319.30	438.40	495.80	513.60	482.70	534.00	552.00	558.40	549.50	565.30	570.80	572.60
7	219.20	337.40	386.10	289.20	418.60	483.30	503.50	468.40	526.90	547.70	555.10	544.80	563.20	569.60	571.70
8	190.80	312.40	364.40	262.00	399.70	471.00	493.70	454.50	519.90	543.50	551.90	540.10	561.00	568.30	570.70
9	166.10	289.20	344.00	237.30	381.60	459.10	484.00	441.00	513.00	539.30	548.60	535.50	558.90	567.10	569.80
10	144.60	267.80	324.70	214.90	364.40	447.50	474.50	427.90	506.20	535.10	545.40	531.00	556.80	565.80	568.80
11	125.90	248.00	306.40	194.70	348.00	436.10	465.20	415.20	499.50	530.90	542.20	526.40	554.70	564.60	567.90
12	109.60	229.60	289.20	176.30	332.20	425.10	456.10	402.90	492.90	526.80	539.00	522.00	552.60	563.30	566.90
13	95.40	212.60	273.00	159.70	317.20	414.30	447.10	390.90	486.40	522.70	535.90	517.50	550.50	562.10	566.00
14	83.10	196.80	257.70	144.60	302.90	403.80	438.40	379.30	480.00	518.70	532.70	513.10	548.40	560.90	565.10
15	72.30	182.20	243.20	131.00	289.20	393.60	429.80	368.10	473.60	514.60	529.60	508.70	546.30	559.60	564.10
16	63.00	168.70	229.60	118.70	276.20	383.60	421.30	357.20	467.30	510.60	526.50	504.40	544.20	558.40	563.20
17	54.00	156.20	216.70	107.50	263.70	373.90	413.10	346.60	461.10	506.70	523.40	500.10	542.10	557.20	562.20
18	47.70	144.60	204.50	97.30	251.80	364.40	405.00	336.30	455.00	502.80	520.40	495.80	540.10	555.90	561.30
19	41.50	133.90	193.10	88.20	240.40	355.20	397.00	326.30	449.00	498.90	517.30	491.60	538.00	554.70	560.40
20	36.20	124.00	182.20	79.90	229.60	346.20	389.30	316.60	443.10	495.00	514.30	487.40	536.00	553.50	559.40
21	31.50	114.80	172.00	72.30	219.20	337.40	381.60	307.20	437.20	491.10	511.30	483.30	533.90	552.30	558.50
22	27.40	106.30	162.40	65.50	209.30	328.80	374.20	298.10	431.40	487.30	508.30	479.20	531.90	551.10	557.60
23	23.90	98.40	153.20	59.30	199.90	320.50	366.80	289.20	425.70	483.60	505.30	475.10	529.90	549.90	556.70
24	20.80	91.10	144.60	53.70	190.80	312.40	359.60	280.70	420.10	479.80	502.40	471.00	527.90	548.60	555.70
25	18.10	84.40	136.50	48.70	182.20	304.50	352.60	272.30	414.50	476.10	499.40	467.00	525.90	547.40	554.80
26	15.70	78.10	128.90	44.10	174.00	296.80	345.70	264.20	409.00	472.40	496.50	463.00	523.90	546.20	553.90
27	13.70	72.30	121.60	39.90	166.10	289.20	338.90	256.40	403.60	468.70	493.60	459.10	521.90	545.00	553.00
28	11.90	67.00	114.80	36.20	158.60	281.90	332.20	248.80	398.30	465.10	490.70	455.20	519.90	543.80	552.00
29	10.40	62.00	108.40	32.80	151.50	274.80	325.70	241.40	393.00	461.50	487.80	451.30	517.90	542.60	551.10
30	9.00	57.40	102.30	29.70	144.60	267.80	319.30	234.20	387.80	457.90	485.00	447.50	516.00	541.40	550.20
31	7.90	53.20	96.50	26.90	138.10	261.00	313.10	227.30	382.70	454.40	482.10	443.60	514.00	540.30	549.30
32	6.90	49.20	91.10	24.30	131.90	254.40	306.90	220.50	377.60	450.80	479.30	439.90	512.00	539.10	548.40
33	6.00	45.60	86.00	22.00	125.90	248.00	300.90	214.00	372.60	447.30	476.50	436.10	510.10	537.90	547.50
34	5.20	42.20	81.20	20.00	120.20	241.70	295.00	207.60	367.70	443.90	473.70	432.40	508.20	536.70	546.50
35	4.50	39.10	76.60	18.10	114.80	235.50	289.20	201.50	362.80	440.40	470.90	428.70	506.20	535.50	545.60
36	3.90	36.20	72.30	16.40	109.60	229.60	283.60	195.50	358.00	437.00	468.20	425.10	504.30	534.30	544.70
37	3.40	33.50	68.30	14.80	104.70	223.80	278.00	189.70	353.20	433.60	465.40	421.40	502.40	533.20	543.80
38	3.00	31.00	64.40	13.40	99.90	218.10	272.60	184.10	348.60	430.30	462.70	417.90	500.50	532.00	542.90
39	2.60	28.70	60.80	12.20	95.40	212.60	267.20	178.60	344.00	426.90	460.00	414.30	498.60	530.80	542.00
40	2.30	26.60	57.40	11.00	91.10	207.20	262.00	173.30	339.40	423.60	457.30	410.80	496.70	529.70	541.10
41	2.00	24.60	54.20	10.00	87.00	201.90	256.80	168.20	334.90	420.30	454.60	407.30	494.80	528.50	540.20
42	1.70	22.90	51.20	9.00	83.10	196.80	251.80	163.20	330.50	417.10	452.00	403.80	492.90	527.30	539.30
43	1.50	21.10	48.30	8.20	79.30	191.80	246.90	158.30	326.10	413.80	449.30	400.40	491.00	526.20	538.40
44	1.30	19.50	45.60	7.40	75.80	187.00	242.00	153.60	321.80	410.60	446.70	396.90	489.20	525.00	537.50
45	1.10	18.10	43.00	6.70	72.30	182.20	237.30	149.10	317.50	407.40	444.10	393.60	487.30	523.90	536.60
46	1.00	16.70	40.60	6.10	69.10	177.60	232.60	144.60	313.30	404.30	441.50	390.20	485.50	522.70	535.70
47	0.90	15.50	38.30	5.50	65.90	173.10	228.10	140.30	309.20	401.10	438.90	386.90	483.60	521.60	534.90
48	0.70	14.40	36.20	5.00	63.00	168.70	223.60	136.20	305.10	398.00	436.30	383.60	481.80	520.40	533.00
49	0.60	13.30	34.10	4.50	60.10	164.40	219.20	132.10	301.00	394.90	433.80	380.30	479.90	519.30	533.10
50	0.60	12.30	32.20	4.10	57.40	160.30	214.90	128.20	297.10	391.90	431.20	377.10	478.10	518.10	532.20
51	0.50	11.40	30.40	3.70	54.80	156.20	210.70	124.40	293.10	388.80	428.70	373.90	476.30	517.00	531.30
52	0.40	10.60	28.70	3.40	52.30	152.30	206.60	120.70	289.20	385.80	426.20	370.70	474.50	515.90	530.40
53	0.40	9.90	27.10	3.00	50.00	148.40	202.50	117.10	285.40	382.80	423.70	367.50	472.70	514.70	529.50
54	0.30	9.10	25.60	2.80	47.70	144.60	198.60	113.70	281.60	379.90	421.20	364.40	470.90	513.60	528.60
55	0.30	8.40	24.10	2.50	45.60	141.00	194.70	110.30	277.90	376.90	418.70	361.30	469.10	512.50	527.80
56	0.20	7.80	22.80	2.30	43.50	137.40	190.80	107.00	274.20	374.00	416.30	358.20	467.30	511.30	526.90

57	0.20	7.20	21.50	2.00	41.50	133.90	187.10	103.80	270.60	371.10	413.80	355.20	465.50	510.20	526.00
58	0.20	6.60	20.30	1.90	39.70	130.50	183.40	100.90	267.00	368.20	411.40	352.10	463.80	509.10	525.10
59	0.20	6.20	19.20	1.70	37.90	127.20	179.80	97.80	263.50	365.30	409.00	349.10	462.00	508.00	524.20
60	0.10	5.70	18.10	1.50	36.20	124.00	176.30	94.90	260.00	362.50	406.60	346.20	460.30	506.90	523.40
61	0.10	5.30	17.10	1.40	34.50	120.90	172.90	92.00	256.50	359.70	404.20	343.20	458.50	505.70	522.50
62	0.10	4.90	16.10	1.20	33.00	117.80	169.50	89.30	253.20	356.90	401.90	340.30	456.80	504.60	521.60
63	0.10	4.50	15.20	1.10	31.50	114.80	166.10	86.70	249.80	354.10	399.50	337.40	455.00	503.50	520.80
64	0.10	4.20	14.40	1.00	30.10	111.90	162.90	84.10	246.50	351.40	397.20	334.50	453.30	502.40	519.90
65	0.10	3.90	13.60	0.90	28.70	109.10	159.70	81.60	243.20	348.70	394.90	331.70	451.60	501.30	519.00
66	0.10	3.60	12.80	0.80	27.40	106.30	156.60	79.20	240.00	346.00	392.50	328.80	449.90	500.20	518.20
67	0.10	3.30	12.10	0.80	26.20	103.60	153.50	76.80	236.80	343.30	390.20	326.00	448.10	499.10	517.30
68	0.00	3.10	11.40	0.70	25.00	101.00	150.50	74.50	233.70	340.60	388.00	323.30	446.40	498.00	516.40
69	0.00	2.80	10.80	0.60	23.90	98.40	147.50	72.30	230.60	338.00	385.70	320.50	444.70	496.90	515.60
70	0.00	2.60	10.20	0.60	22.80	95.30	144.60	70.20	227.60	335.40	383.40	317.30	443.10	495.80	514.70

APPENDIX C

ALPHANUMERIC TO HEXADECIMAL CONVERSION

The following tables show the conversion between binary coded decimal and alphanumeric data. There are two standards that are commonly followed, EBCDIC (Extended Binary Coded Decimal Interchange Code), and USASCII (United States of America Standard Code for Information Interchange).

EBCDIC CHARACTER ASSIGNMENTS

		S/360 Main Storage Bit Positions 0, 1, 2, 3															
Bit Positions 4, 5, 6, 7		0000	0001	0010	0011	0100	0101	0110	0111	1000	1001	1010	1011	1100	1101	1110	1111
	Hex	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
0000	0	NUL	DLE	DS		SP	&	-						{	}	\	0
0001	1	SOH	DC1	SOS						a	j	~		A	J		1
0010	2	STX	DC2	FS	SYN					b	k	s		B	K	S	2
0011	3	ETX	DC3							c	l	t		C	L	T	3
0100	4	PF	RES	BYP	PN					d	m	u		D	M	U	4
0101	5	HT	NL	LF	RS					e	n	v		E	N	V	5
0110	6	LC	BS	EOB / ETB	UC					f	o	w		F	O	W	6
0111	7	DEL	IL	PRE / ESC	EOT					g	p	x		G	P	X	7
1000	8		CAN							h	q	y		H	Q	Y	8
1001	9	RLF	EM						\	i	r	z		I	R	Z	9
1010	A	SMM	CC	SM		¢	!	¦	:								
1011	B	VT				.	$	,	#								
1100	C	FF	IFS		DC4	<	*	%	@								
1101	D	CR	IGS	ENQ	NAK	(	)	_	'								
1110	E	SO	IRS	ACK		+	;	>	=								
1111	F	SI	IUS	BEL	SUB	|	¬	?	"								

Duplicate Assignment

USASCII CHARACTER ASSIGNMENTS

Bit Positions 4, 5, 6, 7		S/360 Main Storage Bit Positions 0, 1, 2, 3															
		0000	0001	0010	0011	0100	0101	0110	0111	1000	1001	1010	1011	1100	1101	1110	1111
	HEX	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
0000	0	NUL	DLE	SP	0	@	P	`	p								
0001	1	SOH	DC1	!	1	A	Q	a	q								
0010	2	STX	DC2	"	2	B	R	b	r								
0011	3	ETX	DC3	#	3	C	S	c	s								
0100	4	EOT	DC4	$	4	D	T	d	t								
0101	5	ENQ	NAK	%	5	E	U	e	u								
0110	6	ACK	SYN	&	6	F	V	f	v								
0111	7	BEL	ETB	'	7	G	W	g	w								
1000	8	BS	CAN	(	8	H	X	h	x								
1001	9	HT	EM	)	9	I	Y	i	y								
1010	A	LF	SUB	*	:	J	Z	j	z								
1011	B	VT	ESC	+	;	K	[	k	{								
1100	C	FF	FS	,	<	L	\	l	¦								
1101	D	CR	GS	-	=	M	]	m	}								
1110	E	SO	RS	.	>	N	¬	n	~								
1111	F	SI	US	/	?	O	_	o	DEL								